

S P E C I F I C A T I O N

Docket No. **SILA0004**

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I, **Donald A. Kerth**, a citizen of the United States of America, residing in the State of Texas, have invented new and useful improvements in a

CHOPPED INTERMEDIATE FREQUENCY WIRELESS RECEIVER

of which the following is a specification:

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention relates to wireless communication in general, and in particular to wireless transceivers. Still more particularly, the present invention relates to a chopped intermediate frequency wireless receiver.

2. Description of Related Art

Unlike wireline communication environments, a wireless communication environment has to accommodate a large number of users sharing different parts of the frequency spectrum with very strong signals coexist adjacent to very weak signals. Hence, a wireless receiver should be able to select the signal of interest while rejecting all other signals. According to their respective architecture, wireless receivers can generally be classified under two categories, namely, homodyne receivers and heterodyne receivers.

With a homodyne receiver, the desired signal is initially selected by a bandselect filter and is subsequently amplified by a low-noise amplifier. The desired signal is then frequency translated by a mixer to DC before other baseband operations are performed on the desired signal. With a heterodyne receiver, the desired signal is sent through receiver components similar to those in the homodyne receiver with the exception that the desired signal is translated to an intermediate frequency (IF) when signal processing operations are performed.

For heterodyne wireless receivers, image rejection refers to the ability to select the desired signal from the image of the desired signal spaced away by twice the IF signal. Basically, a heterodyne wireless receiver should be able to select the desired signal from its image. Otherwise, the subsequent detector circuit within the heterodyne wireless

1 receiver will not be able to distinguish between the desired signal and the image signal, and
2 the output becomes the superposition of both signals. Accordingly, image rejection is one
3 of the problems that are faced by designers of heterodyne wireless receivers.
4

5 Also, in many wireless receiver designs, all internally used oscillator
6 frequencies are derived from a single high-accuracy reference oscillator, which can produce
7 interference at fundamental, harmonic and sub-harmonic frequencies of the reference
8 oscillator. The mixing of such interference frequencies with unwanted input signals is
9 referred to as a spurious signal. Spurious signals are commonly found in wireless receivers.
10 A wireless receiver may down convert a spurious signal that can interfere with the desired
11 signal of interest, and as a result, the desired signal of interest can be corrupted.
12

13 The present disclosure provides a method and apparatus for alleviating the
14 above-mentioned problems within a wireless receiver.

SUMMARY OF THE INVENTION

In accordance with a preferred embodiment of the present invention, a wireless receiver includes a local oscillator (LO), a first and a second mixers, an LO frequency control module, an intermediate frequency (IF) filter, a digital down converter and a down conversion controller. The LO provides a local oscillating signal to the first and second mixers. The first and second mixers converts a received radio frequency signal to an in-phase IF signal and a quadrature IF signal, respectively. The LO frequency control module alternately down converts a channel frequency by changing an oscillation frequency of the LO. Coupled to the digital down converter, the down conversion controller adjusts a complex sine wave within the digital down converter while the in-phase IF signal and the quadrature IF signal are being down-converted by the digital down converter to a baseband signal.

Alternatively, a wireless receiver includes an LO, a first and a second mixers, an LO frequency control module, an IF filter, a switch and a digital down converter. The LO provides a local oscillating signal to the first and second mixers. The first and second mixers converts a received radio frequency signal to an in-phase IF signal and a quadrature IF signal, respectively. The LO frequency control module alternately down converts a channel frequency by changing an oscillation frequency of the LO. Coupled to the IF filter, the switch alternately swaps signals paths of the in-phase IF signal and the quadrature IF signal on a frame-by-frame basis in synchronization with the LO frequency control module. The digital down converter subsequently down-converts the in-phase IF signal and the quadrature IF signal to a baseband signal.

All features and advantages of the present invention will become apparent in the following detailed written description.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention itself, as well as a preferred mode of use, further objects, and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is a block diagram of a chopped intermediate frequency wireless receiver, in accordance with a preferred embodiment of the present invention;

Figure 2 is a block diagram of a chopped intermediate frequency wireless receiver, in accordance with an alternative embodiment of the present invention;

Figures 3a-3b graphically illustrate the potential improvements in the interference performance of a chopped intermediate frequency wireless receiver with respective to image rejection; and

Figures 4a-4d graphically illustrate the potential improvements in the blocking performance of a chopped intermediate frequency wireless receiver with respective to spurious signals.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Referring now to the drawings and in particular to Figure 1, there is depicted a block diagram of a chopped intermediate frequency (IF) radio frequency (RF) receiver, in accordance with a preferred embodiment of the present invention. As shown, a RF receiver 10 includes an antenna 11, a low-noise amplifier 12, a pair of RF mixers 13a-13b, an IF filter 15, an analog-to-digital converter (ADC) 16 and a digital down converter 18 along with additional receiver circuitry (not shown) that are well-known to those skilled in the art. In addition, RF receiver 10 includes a radio frequency local oscillator (RFLO) 14 coupled to RF mixers 13a-13b for generating an in-phase signal and a quadrature signal. RF receiver 10 also includes an LO frequency control module 19 coupled to RFLO 14 for controlling the oscillation frequency of RFLO 14. Similarly, a down conversion controller 30 is coupled to a digital complex sinusoid signal IFLO 17 for controlling the oscillation frequency of IFLO 17 that is connected to digital down converter 18.

RF signals are initially received by antenna 11. After passing through low-noise amplifier 12, the RF signals enter an in-phase path 2 and a quadrature path 3 via a junction 4. A first input of RF mixer 13a is connected to in-phase path 2, and a second input of RF mixer 13a is connected to an in-phase output of RFLO 14. The output of RF mixer 13a provides in-phase IF signals to IF filter 15 via an in-phase signal path I. Similarly, a first input of RF mixer 13b is connected to quadrature path 3, and a second input of RF mixer 13b is connected to a 90° out-of-phase output of RFLO 14. The output of RF mixer 13b provides quadrature IF signals to IF filter 15 via a quadrature signal path Q. Both IF signal paths for RF receiver 10 may be approximately 200 kHz.

In the embodiment as shown in Figure 1, the IF signals within in-phase signal path I and quadrature signal path Q of RF receiver 10 are completely independent from each other until the final down conversion to a baseband signal. In other words, each of the IF signal paths I and Q does not have a complex transfer function. Because the

transfer functions for the IF signal paths I and Q are real, the desired signal can be down converted to a +200 kHz IF signal or a –200kHz IF signal by changing the oscillation frequency of RFLO 14.

Under time-division multiple access (TDMA), data are typically interleaved several times and are collected in TDMA frames. Thus, the above-mentioned IF signals down conversion can be performed on a frame-by-frame basis by simply utilizing LO frequency control module 19 to control the oscillation frequency of RFLO 14. Preferably, the oscillation frequency of RFLO 14 is modified as follows:

$$\begin{aligned} \text{even frame:} \quad & f_{\text{RFLO}} = f_{\text{CH}} - f_{\text{IF}} \\ \text{odd frame:} \quad & f_{\text{RFLO}} = f_{\text{CH}} + f_{\text{IF}} \end{aligned}$$

Alternatively, the oscillation frequency of RFLO 14 can be modified as follows:

$$\begin{aligned} \text{even frame:} \quad & f_{\text{RFLO}} = f_{\text{CH}} + f_{\text{IF}} \\ \text{odd frame:} \quad & f_{\text{RFLO}} = f_{\text{CH}} - f_{\text{IF}} \end{aligned}$$

where f_{RFLO} = oscillation frequency of RFLO 14

f_{CH} = frequency of channel

f_{IF} = frequency of IF signals

Basically, the IF signal down conversions are performed as a complex sinusoidal multiplication on the RF signals as follows:

$$IF(t) = RF(t) \times e^{-2\pi f_{\text{RFLO}} t}$$

where $f_{\text{RFLO}} = f_{\text{CH}} \pm f_{\text{IF}}$

No adjustment or modification to the IF signal paths I and Q within RF receiver 10 is required.

The final down conversion of the IF signals to a baseband signal can be performed by one of the following two methods. The first method is by adjusting the digital complex sine wave used in the final down conversation within a digital down converter such as digital down converter 18. Specifically, the digital complex sine wave used in digital down converter 18 is adjusted by adjusting the frequency of IFLO 17 via down conversion controller 30. Preferably, the adjustment is performed as follows:

$$\begin{aligned} \text{even frame: } IFLO(t) &= e^{-j\omega_{IF}t} \\ \text{odd frame: } IFLO(t) &= e^{+j\omega_{IF}t} \end{aligned}$$

Alternatively,

$$\begin{aligned} \text{even frame: } IFLO(t) &= e^{+j\omega_{IF}t} \\ \text{odd frame: } IFLO(t) &= e^{-j\omega_{IF}t} \end{aligned}$$

$$\begin{aligned} \text{where } e^{-j\omega_{IF}t} &= \cos\omega_{IF}t - j\sin\omega_{IF}t \\ e^{+j\omega_{IF}t} &= \cos\omega_{IF}t + j\sin\omega_{IF}t \\ \omega_{IF} &= 2\pi f_{IF} \end{aligned}$$

No adjustment or modification to the IF signal paths I and Q within RF receiver 10 is required.

The second method for performing down-conversion of IF signals is to use a switch to swap the two IF signal paths (from +200 kHz to -200 kHz) before the down-conversion stage. The second method is further illustrated in details in Figure 2.

With reference now to Figure 2, there is depicted a block diagram of a chopped IF RF receiver, in accordance with an alternative embodiment of the present invention. As shown, a RF receiver 20 includes an antenna 21, a low-noise amplifier 22, a pair of RF mixers 23a-23b, an IF filter 25, an ADC 26, a switch 27 and a digital down converter 28 along with additional receiver circuitry (not shown) that are well-known to those skilled in the art. In addition, RF receiver 20 includes a RFLO 24 coupled to RF

1 mixers **23a-23b**. RF receiver **20** also includes an LO frequency control module **29** coupled
2 to RFLO **24** for controlling the oscillation frequency of RFLO **24**.

3
4 In essence, the basic functional components of RF receiver **20** are similar to
5 those of RF receiver **10** from Figure 1. The main difference between RF receiver **20** and
6 RF receiver **10** from Figure 1 is that instead of using a IFLO and a down conversion
7 controller to adjust the digital complex sine wave used in a digital down converter, a
8 switch, such as switch **27**, is used to swap every other frame between the IF signal paths
9 I and Q. For example, in switch **27** of Figure 2,

10 even frame: node **a** connects to node **b**; node **c** connects to node **d**

11 odd frame: node **a** connects to node **d**; node **c** connects to node **b**

12
13 Alternatively,

14 even frame: node **a** connects to node **d**; node **c** connects to node **b**

15 odd frame: node **a** connects to node **b**; node **c** connects to node **d**

16
17 In both of the above-mentioned cases, nodes **a** and **b** are connected to the IF signal path
18 I, and nodes **c** and **d** are connected to the IF signal path Q. Although switch **27** is shown
19 to be located between ADC **26** and digital down converter **28** in Figure 2, switch **27** can
20 be located anywhere within the IF signal paths. For example, switch **27** can be located
21 between IF filter **25** and ADC **26** or between RF mixers **23a-23b** and IF filter **25**.

22
23 Referring now to Figures **3a-3b**, there are graphically illustrated the potential
24 improvement in the interference performance with respect to image rejection within a
25 chopped IF wireless receiver, such as RF receiver **10** in Figure 1 and RF receiver **20** in
26 Figure 2, by swapping IF signal frequencies. Figure **3a** represents even numbered frames
27 (*i.e.*, +200 kHz IF signals), and Figure **3b** represents odd numbered frames (*i.e.*, -200 kHz
28 IF signals). As shown in Figure **3a**, because of the limited image rejection, a -400 kHz
29 reference interferer **31** images into the +200 kHz side as an interference signal **32** on the

1 even frames. As a result, interference signal **32** interferes with a desired signal **33**. In
2 Figure **3b**, the -400 kHz reference interferer **35** does not image into a desired signal **34** on
3 the odd frames. Because of the present invention, the odd frames will not "see" the
4 mirrored interference for a -400 kHz reference interferer. Hence, the overall carrier/
5 interference (C/I) ratio is improved by approximately 3 dB since only half of the frames
6 are affected by the mirrored reference interference.

7
8 With reference now to Figures **4a-4b**, there is graphically illustrated the
9 potential improvement in the blocking performance with respect to spurious response
10 within a chopped IF wireless receiver, such as RF receiver **10** in Figure **1** and RF receiver
11 **20** in Figure **2**, by swapping IF signal frequencies. As shown, Figure **4a** represents a
12 RFLO signal f_{RFLO} and a spurious response f_{spur} , and Figure **4b** represents a desired signal
13 **41** and an undesired signal **42**. Figure **4c** represents even numbered frames (*i.e.*, $+200$ kHz
14 IF signals), and Figure **4d** represents odd numbered frames (*i.e.*, -200 kHz IF signals).
15 During the operation of a wireless receiver, RFLO signal f_{RFLO} mixes with desired signal
16 **41** to produce desired signals **44** and **45** in Figures **4c** and **4d**, respectively. Similarly,
17 spurious response f_{spur} mixes with undesired signal **42** to produce spurious signals **43** and
18 **46** in Figures **4c** and **4d**, respectively.

19
20 Typically, the spurious response of a wireless receiver does not change when
21 the frequency of a RFLO is adjusted. Therefore, as the frequency of the RFLO is adjusted
22 on a frame-by-frame basis (*i.e.*, swapping the IF signal from $+200$ kHz to -200 kHz), the
23 spurious signal down-converted to IF will be either a $+200$ kHz interference signal or a -200
24 kHz interference signal. Either way, as the signal is swapped between $+200$ kHz and -200
25 kHz, alternate frames will not "see" the wanted signal degraded by the spurious signal.
26 Hence, spurious signal **42** mixes into the $+200$ kHz side on even frames and interferes with
27 desired signal **44**; but spurious signal **42** does not mix into desired signal **45** on the odd
28 frames. As a result, the overall signal quality of the wireless receiver is improved because
29 of the present invention.

1 As has been described, the present invention provides a chopped IF wireless
2 receiver. The present invention improves the quality of a signal within a wireless receiver
3 by swapping the IF signal frequency on a frame-by-frame basis. One main advantage of
4 the present invention is that no adjustment to the IF signal paths I and Q is required for the
5 swapping of the IF signal frequency.

6
7 The method and apparatus of the present invention are applicable to RF
8 receivers suitable to be used in TDMA communication networks, such as Global System
9 for Mobile communications (GSM) networks. Although a RF receiver is used to illustrate
10 the present invention, it is understood by those skilled in the art that the present invention
11 is also applicable to the receiver portion of wireless transceivers.

12
13 While the invention has been particularly shown and described with reference
14 to a preferred embodiment, it will be understood by those skilled in the art that various
15 changes in form and detail may be made therein without departing from the spirit and scope
16 of the invention.